APPLICATION OF SATELLITE DATA FOR MAPPING AND MONITORING WETLANDS

Fact Finding Report

Federal Geographic Data Committee
Wetlands Subcommittee

Technical Report 1
September 1992

Federal Geographic Data Committee
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Department of Transportation • Environmental Protection Agency
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National Aeronautics and Space Administration • National Archives and Records Administration
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Federal Geographic Data Committee

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The following is the recommended bibliographic citation for this publication:
Federal Geographic Data Committee. 1992. Application of Satellite Data for Mapping and Monitoring Wetlands - Fact Finding Report; Technical Report 1. Wetlands Subcommittee, FGDC. Washington, D.C. 32 pages plus Appendices.

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EXECUTIVE SUMMARY

The detail and reliability of information derived from satellite data have steadily improved. These improvements include advancements in spatial and spectral resolution, georeferencing, and digital image processing techniques, along with growing experience using satellite data. Significant strides have been made in integrating ancillary data, such as soils and digital elevation models, into the classification of satellite data. This integration is dependent upon the use of geographic information system (GIS) technology. Stream gauging data and rainfall data are now being used to select the best scenes for wetland identification. Even with these improvements, satellite data can not match the accuracy of areal extent, classification detail, or reliability that can be extracted from conventional aerial photography using manual photo-interpretation techniques, such as those used by the U.S. Fish and Wildlife Service's (FWS) National Wetlands Inventory (NWI) Project. However, for some regions, satellite remote sensing may be the most cost-effective means for conducting reconnaissance wetland surveys.

The power of satellite imagery lies in its ability to be easily integrated with all other sources of data in a GIS, contributing to the accuracy of the GIS. The U.S. Department of Agriculture's Soil Conservation Service (SCS) believes that satellite technology can help to classify certain administrative classes of wetlands legislated by the Farm Bills of 1985 and 1990. Many other resource managers have complained that, in practical application, the promise of space-based remote sensing has not measured up to NWI actual performance. The subcommittee believes satellite data, when used in conjunction with NWI digital data produced through the use of aerial photography, can and do provide a tool for monitoring water levels in wetlands and monitoring the cover change of adjacent uplands. Synergistic effects created by combining both satellite data and NWI digital data have greater value than using either data source alone. Such data sets have the potential to be synoptic and accurate.

INTRODUCTION

The President's Domestic Policy Council's Wetlands Task Force requested that the Federal Geographic Data Committee's Wetland Subcommittee produce a report about the application of satellite data for mapping and monitoring of wetlands. On January 14 and 15, 1992, the subcommittee held a meeting to discuss the current application of satellite data for mapping and monitoring of wetlands. The subcommittee invited top level technical experts from the following organizations to address a preset list of questions and describe their experiences:

Earth Observation Satellite Company (EOSAT)
SPOT Image Corporation (SPOT)
Ducks Unlimited (DU)
U.S. Environmental Protection Agency, Environmental Monitoring Systems Laboratory (EPA)
National Oceanic and Atmospheric Administration (NOAA) Coast Watch

Change Analysis Program (C-CAP)
A. Oak Ridge National Laboratory
B. University of Delaware
Earth Satellite Corporation
U.S. Geological Survey (USGS), Earth Resources Observation System (EROS) Data Center (EDC)
Maryland Department of Natural Resources, Water Resources Administration (MD-DNR)

On January 15, 1992, the Wetlands Subcommittee met to discuss the information gained from the previous days presentations, and to compare notes on the presentation of each speaker. The subcommittee drafted a fact-finding report that analyzed and consolidated the responses resulting from the January 14, 1992, meeting.

Upon review of the draft report, SCS reviewers believed that the report did not fully reflect the latest findings in the use of satellites for mapping and monitoring wetlands. NASA's Space Remote Sensing Center (SRSC) is conducting research and mapping wetlands for SCS in accordance with the Farm Bills of 1985 and 1990. SRSC's experience in mapping wetlands with satellite data has been primarily related to inventory efforts conducted by the SCS. Accuracy assessments conducted for the States of Mississippi and Arkansas by the SCS for every county in the Yazoo basin showed results that were superior to the original suggested SCS wetlands mapping techniques. As a result, the wetland classification used by SRSC for the Yazoo basin in the States of Mississippi and Arkansas is currently being used as baseline data for the SCS. SCS personnel have commented that, for this region, satellite remote sensing proved to be the only accurate and cost effective means of conducting a wetlands inventory for their agency. SRSC's mapping approach has yet to be documented in detail or published in the technical literature.

On May 4, 1992, the Wetlands Subcommittee invited SRSC to make a presentation on their applications and to respond to the same questions answered by the speakers at the January 14, 1992 meeting. Employees from the SCS's National Cartographic and GIS Center (NCG) also made a presentation at the May 4th meeting. The SRSC and NCG presenters were not questioned by peer technical experts as were the presenters at the January 14, 1992, fact-finding meeting. This report includes the analysis and consolidated responses from both the January 14, 1992, and May 4, 1992, meetings.

In many instances, DU answers and/or experiences are the only ones listed. This is because DU's Dr. Gregory Koeln was the first speaker and provided his answers in writing. Where subsequent speakers agreed with Dr. Koeln, his answer or experience was used. If subsequent speakers had different answers or additional experiences, these were included.

DISCUSSION

The current limitations of satellite data that result in diminished utility for and accuracy of wetland identification and habitat classification can be categorized into two areas:

a. Spectral Resolution

Spectral resolution problems result when the reflected radiance of different land covers are very similar. Different land covers with similar radiance have been placed in the same classification unit; for example, drier forested wetlands being classified as upland forests; wetter scrub-shrub wetlands being classified as either forested wetlands or emergent wetlands; drier scrub-shrub wetlands being classified as upland forests; shadows from forested areas falling onto agricultural lands being classified as emergent wetlands; large, dense formations of tall emergent wetland plants, such as Phragmites spp., being classified as upland grassland or even upland deciduous forests; and high coastal marsh, during low tide, being identified as upland grassland. These problems in spectral resolution occur when the satellite imagery is taken at a very wet time of the year or during a drought. Many of the spectral resolution problems can be resolved or ameliorated by using satellite imagery from several time periods that best display wetland conditions. The process of merging multitemporal scenes would result in profound cost increases for National programs, as well as limit data useability for detecting change.

b. Spatial Resolution

Each thematic mapper (TM) pixel represents an area 30 by 30 meters. Theoretically, spatial resolution is defined as two pixels -- that is, a box two pixels on a side, or a total of four pixels (approximately 1 acre for TM data). In practice, however, it generally takes a box with three identical pixels on a side (nine pixels or approximately 1.5 acres) to consistently identify an object. If the object being classified does not have a square shape, or if the adjacent land cover has a similar reflected radiance, or if one or more of the pixels has a slightly different radiance, then the number of pixels needed to make a consistently confident determination increases. Although wetlands smaller than the theoretical limit have been accurately delineated, some scientists believe they need as many as 25 pixels (approximately 5 acres) to be confident about certain classification units. Other scientists believe that 25 pixels is a worse case scenario. Through the uses of ancillary data and visual interpretation, smaller wetlands can be successfully identified in treeless areas when the basin is nonvegetated, full of water, and surrounded by the bare soil of an agricultural field or much drier prairie grass that has a significantly different spectral reflectance.

Spatial resolution has often been presented as the main shortcoming of wetlands mapping by satellite. In reality, the greater concern is the spectral resolution that results in the failure to distinguish wetlands from uplands. However, it is the spectral resolution that now allows us to see differences in biomass and may allow us in the future to determine the health of wetlands.

Not all wetland mapping has the objective of assigning habitat classifications to mapped wetlands, as does the NWI. For instance, the SCS's Swampbuster Program merely attempts to identify wetlands and assign to each entity one of a few operational classifications (prior converted cropland, farmed wetland, wetland, artificial wetland, etc.). If the need for mapping is merely to identify wetlands in farm fields and to update wetland maps produced by other means, then satellite imagery obtained when the wetlands are flooded may be appropriate for this use, especially when supplemented with aerial photography; however, this imagery may not be appropriate for habitat classification.

After deleting all point and linear wetland data, DU compared wetland basins delineated in the DU wetland classification using TM data for basins identified on wetland maps prepared by the NWI on the treeless prairies. With this method, approximately 20 percent of the wetlands smaller than 2 acres (9 pixels) were detected; 70 percent of the basins between 2 and 5 acres (9-25 pixels) were detected; 91 percent of the basins between 5 and 10 acres (23-45 pixels) were detected; and all basins greater than 25 acres (112 pixels) were detected. Manual editing of the DU wetland data has allowed a greater number of smaller basins to be detected. DU believes that under optimum conditions, blocks of forested wetland and scrub-shrub wetlands smaller than 10 acres cannot be reliably detected using TM. SRSC, however, believes that deciduous forested wetlands as small as one acre can be identified with TM data in the Yazoo basin of the States of Mississippi and Arkansas. This assumes that multiple dates of imagery are evaluated, at least one of which is acquired during a leaf off period when flooding has occurred for the proper number of days during the growing season or when the flood event can be correlated to the appropriate river stage at a local stream gauging station. The criteria for the appropriate river stage is the minimum stage that produces 15 days of consecutive flooding with 50 percent occurrence, i.e. on the average once in two years. Riparian specialists believe that the mapping width of at least 60-90 meters essentially precludes the utility of satellite data for mapping most riparian areas.

Benefits in using satellite data for monitoring wetlands and upland land cover and land use include:

1. the synoptic overview of redundant regions;
2. data collected in a digital format, which facilitates the use of repeat coverage to enhance results;
3. ease of integration of the data with other digital data themes;
4. repeat coverage, which facilitates monitoring seasonal or yearly changes and allows data to be tied to rainfall events or river gauge data;
5. lower cost per acre than aerial photography; faster results in mapping;

6. spectral sensing of mid-infrared bands of TM data, which provide better wetland detection than data from the multispectral scanner (MSS) or similar spectral range sensors;
7. combination of the Landsat TM data with NWI data, which provided better information as to the value of the wetland habitat for waterfowl than the NWI data used alone.

Limitations in the use of satellite data for monitoring wetlands and upland habitats are:

1. reduced accuracy and detail in identifying certain wetland habitat types when compared to aerial photography;
2. inability to classify more than a limited number of wetland classes;
3. inability to reliably and routinely detect forested wetland and scrub-shrub wetlands;
4. significant problems in trying to identify vegetated wetlands with drier water regimes;
5. difficulty differentiating emergent vegetation growing in dry basins from some upland vegetation types;
6. underestimations of the acreage of individual wetlands; the amount of underestimation is not consistent;
7. difficulty detecting wetland basins less than 2 acres (even in treeless areas);
8. very limited ability to detect by satellite observation alone small wetland filling on the margins of wetlands ("nibbling");
9. aggregation of complexes of wetlands with dendritic drainage patterns and a variety of other wetland classes into one simple class;
10. inability to map most riparian areas because of spatial resolution;
11. weather conditions preclude data acquisition on desired dates (this also applies to aerial photography but not to the same extent);
12. clouds, cloud shadows, and, in areas of high relief, terrain shadows cause spectral signatures that are confused with land cover types;
13. uncertainty as to whether data from Landsat 6 (to be launched in early 1993) will be collected if there is no order for the data. Such a practice will reduce the number of scenes that will be collected and available for use in multi-temporal analysis.

These limitations apply to wetland classification schemes that are focused on mapping wetland habitats. They do not apply to all classification systems. For example, limitations 1, 2, 3, 4, 5, 9, and 10 do not apply to mapping conducted as part of the SCS Swampbuster Program, which is based primarily on recertification and compliance checking of nonvegetated farmed wetlands for the 1985 and 1990 Farm Bills.

CONCLUSIONS

Satellite data can be used to monitor water levels of some wetlands and changes in a number of habitat types, and to inventory and determine changes in upland cover. Satellite technology cannot be used for inventories of wetlands for the purpose of wetland identification and classification without also using other data sources. If there are no other data sources available, it can be used for reconnaissance wetland surveys. Digital satellite data facilitates integration of multiple data sets in GIS applications.

The current satellite technology is most valuable when used in conjunction with digital data derived from aerial photography and other sources; this technology cannot be used to classify wetland types as defined by the FWS wetland classification system entitled "Classification of wetlands and deepwater habitats of the United States" (Cowardin and others 1979). Most scientists believe that to adequately delineate and classify wetlands, one needs 5-meter resolution (or better) color-infrared data viewed stereoscopically. In certain instances, satellite information is not only extremely helpful in inventorying wetlands, it may be the best or only tool available at any given time. A case in point is farmed wetlands located in the Yazoo basin of Mississippi and Arkansas. These wetlands have had their natural vegetation removed and hydrology altered. Therefore, soils and vegetation offer little in terms of identifying wetland characteristics. The only practical way to identify these wetlands is by documenting wetland hydrology from offsite information (e.g. stream gauge data, aerial photographs, satellite information, etc.). Because aerial photographs are not generally available in a sequence that would depict frequency and duration of inundation, their utility is limited in this basin. However, satellite data repeat coverage correlated to steam gauge data can provide information of frequency and duration of inundation, which can be directly tied to wetland hydrology criteria, thus identifying certain types of wetlands. Acquiring cloud-free data during the optimum time period (e.g. flooding) for delineating wetlands is at best a hit or miss proposition. Even if satellite collection coincides with flooding, lingering clouds often reduce data usefulness.

The following points must be considered prior to an effort to expand the satellite capabilities of the industry.

1. The best technique for initial wetland habitat mapping and inventory is the technique currently used by the FWS's NWI project, which uses aerial photography.

2. Digital NWI data and satellite data are easily merged to provide products with greater wetland evaluation and monitoring capabilities than either type of data used alone. Digital data for all NWI maps are required. The subcommittee believes it makes little sense to expand the satellite capabilities for wetland monitoring in the U.S. if the NWI process is not accelerated and all NWI final maps are not digitized.

3. An important obstacle in using current satellite technology for wetland monitoring is the lack of cloud-free data acquired during the optimum time period (when all wetlands are inundated or fully saturated to their upland margin and not beyond). During years of normal precipitation, this may only be for a two to three week period each year. Currently, the opportunity to acquire TM data only every 16 days (8 days if you include Landsat 4) is not sufficient. With adjustable viewing angles, SPOT has a very high rate of acquisition opportunities, up to 11 times every 26 days. Oblique views, however, will increase the difficulty of ground registration particularly in areas of high relief displacement. SPOT also offers radar imagery. Limited resolution of radar data, however, limits its effectiveness for monitoring surface hydrology in wetland areas. There are various means of overcoming this obstacle. One way to increase the odds of obtaining cloud-free data is to use multiple satellites. The costs of maintaining multiple satellites will be high, but in the early years of the Landsat program, it was generally accepted that multiple satellites would be needed if acquisition of cloud-free data for operational programs was required. Another means of partially overcoming the problem of cloud cover is to develop satellites that can readily modify the look angle (as SPOT can) to provide more frequent coverage for areas of interest.

   DU has worked with radar data. Many technical obstacles remain before radar data can be used operationally to monitor wetland inundation and saturation, but DU is encouraged that radar may provide an additional tool for wetland monitoring. Development of satellite systems with radar capabilities could be one solution for acquiring cloud-free data at the optimum time for wetland monitoring.

4. In efforts to promote the expansion of satellite systems for wetland monitoring, we should de-emphasize the use of today's satellite systems as the primary source for wetland inventories and emphasize the use of satellite systems for monitoring wetlands and evaluating wetland functions in conjunction with other data sources. Wetland mappers must make their specifications and data requirements known to the people designing Landsat 7, which is scheduled for launch in 1997. Information and data needs should be forwarded through appropriate organizational channels.

   Current satellite data and the capabilities of satellite systems in the near future cannot be used to accurately classify the wetland type nor to accurately delineate the wetland margins for all existing wetlands. Using satellite data in addition to NWI digital data provides a tool for monitoring water conditions of wetlands, examining impacts to wetlands, and ascertaining the point-in-time value of wetlands.

   In many countries, either the value of wetland has not been recognized or funds for the type of mapping provided by the NWI are not available. DU has worked very successfully in both Canada and Mexico to provide reconnaissance wetland maps using Landsat TM technology. The products are not as accurate or detailed as those produced in the United States by the NWI, but in many cases, they represent the best and only source of wetland data over these regions.

EXAMPLES OF COMBINING SATELLITE AND DIGITAL DATA DERIVED FROM AERIAL PHOTOGRAPHY

The following are examples of how FWS digital NWI data could be combined with satellite data to produce a product having greater value than using either data source alone.

1. Maps have been produced for Maryland using SPOT 10-meter data as an image base and using NWI vectors as an overlay. This combination provides a valuable and cost effective tool for informing and educating the public on wetlands.

2. Many environmental impacts to wetlands result from misuse of the surrounding uplands. Satellite data can be used to analyze these impacts at a lower per acre cost and results can be produced faster than with aerial photogrammetry.

3. Satellite data can be used to identify regions where rapid changes in wetlands are taking place. As a result, these areas may require frequent updates. Updates should use aerial-photography-based NWI techniques.

4. Current satellite capabilities limit the use of satellite data for updating NWI maps. Some of the satellite systems being planned may have the capabilities to update NWI maps. However, even with the improved satellite capabilities, it is not certain whether these systems can adequately implement the full FWS wetland classification system, or whether they can implement a simplified version.

5. Satellite technology is a tool to provide current status of water levels in wetlands. Satellite data can readily be used to ascertain the extent of inundation and saturation of nonvegetated wetlands at a point in time.

FACT FINDING QUESTIONS AND ANSWERS

The following questions and answers provide specific insights into the status of mapping wetlands using satellite imagery.

1. Is any data being currently collected over the conterminous United States (U.S.) for which no order has been previously placed?

   Answer: Yes

EOSAT

EOSAT's data acquisition policy is to acquire daytime data on all passes over the conterminous U.S. whether or not an order has been placed for it.

SPOT

The SPOT satellite is constantly acquiring imagery over the U.S., including Alaska and Hawaii. Client acquisition requests are priority. Regardless of client acquisition requests, it is SPOT's goal to acquire total area coverage of the U.S. Intelligent archive building is used to build a historical database with the first priority being near-vertical panchromatic 10-meter and multispectral 20-meter data. The second priority is oblique panchromatic and multispectral imagery for change detection and stereoscopic terrain modeling.

2. Is any TM data being processed today?

   Answer: Yes

EOSAT

EOSAT acquires Landsat TM data every day. Customer orders are processed on an image generation computer system designed to process data from Landsats 4, 5, and 6. This system became operational on October 1, 1991.

The Landsat 4 and 5 archive contains 28225 TM scenes in the conterminous United States with less than 10 percent cloud cover for the period July 1982 to January 1991. Of these scenes, 1598 were acquired of the East Cost between the months of March and October, inclusive. EOSAT can provide more detailed information about specific regions at any time.

SPOT

SPOT also acquires multispectral data everyday. SPOT imagery is being processed today from the SPOT 2 satellite. SPOT 1 has been reactivated to increase acquisition of imagery during the growing season, specifically for current clients and for archive building in relation to vegetation and wetland studies. The panchromatic 10-meter-resolution imagery is being used in forestry, oil and gas research, urban planning, communications, and defense applications. The multispectral 20-meter-resolution imagery is being used in land cover classifications and vegetative analysis. Multispectral imagery is being used by several Federal agencies due to high resolution, rapid revisit capability (capability to acquire 11 images every 26 days), and commercial delivery capability.

SPOT is devoted to total quality management in regards to every step in the delivery of its data and service to its clients. There is a 10 line drop minimum data specification in its quality control process. Cloud cover rating is confirmed prior to final production of all deliveries. Full technical support is provided after delivery of product.

Ducks Unlimited

On January 9, 1992, the Landsat TM scenes listed in table 1 were being processed. Some of the scenes were being classified, but the majority of the scenes were being grouped and edited to wetland and, in some cases, upland classes.

Table 1. Landsat TM scenes being processed by Ducks Unlimited on January 9, 1992

Path	Row	Geographic Area	Ducks Unlimited Office
22	26	Central Ontario	Winnipeg, Manitoba
26	42	Laguna Madre, Mexico	Long Grove, Illinois
26	43	Laguna Madre, Mexico	Long Grove, Illinois
26	42	Laguna Madre, Mexico	Monterrey, Mexico
29	28	North Dakota, South Dakota Minnesota	Long Grove, Illinois
32	43	Pabellon, Mexico	Long Grove, Illinois
33	25	Southwest Manitoba	Winnipeg, Manitoba
39	23	West Central Saskatchewan	Regina, Saskatchewan
40	23	East Central Alberta	Edmonton, Alberta
66	14	Yukon Flats, Alaska	Long Grove, Illinois

3. How much did the last satellite scene cost that your organization purchased and how long did it take to receive it?

Answer:
EOSAT sells a full, system-corrected scene for $ 4,400. SPOT data costs $2,450 per computer-compatible scene, either panchromatic or multispectral. Both EOSAT and SPOT currently deliver products in less than quoted delivery time. Landsat MSS data more than 2 years old is available for $200 from EDC. Special acquisition fees are extra. Scenes take 4-8 weeks for delivery. Standard archived scenes are delivered in less than one week.

See Appendixes B and C for SPOT and EOSAT fee schedules and detailed cost information for a variety of formats. When comparing the price lists for SPOT and EOSAT data it is important to realize that a full SPOT scene covers approximately one-eighth the area of a full Landsat TM scene.

Ducks Unlimited

In its most recent order, DU purchased three full Landsat TM scenes of Mexico. The order was faxed to EOSAT on December 18, 1991. DU received the order 19 days later on January 6, 1992. Cost per satellite scene was $2200 (one-half the normal price). DU was able to buy the data at one-half the normal price because of a sale EOSAT offered 1991 buyers of satellite data. The scenes DU purchased in 1991 will be used to examine wetland changes. The scene previously ordered on September 9, 1991, was received on December 7, 1991, more than 12 weeks later.

EPA

It took the Environmental Protection Agency (EPA) over a year to acquire all 16 scenes necessary for the Chesapeake Bay watershed characterization project. The scenes varied over a four year time span. This was due to cloud cover problems, even though one base year would have been desirable. This experience showed EPA how helpful multiple satellites and constant acquisition would have been for obtaining full study area coverage with better date consistency.

4. Is each analysis performed as a unique operation, or can it be performed on a routine basis on different scenes?

Answer:
Each data user performs a standard set of operations on raw satellite data as a first step, but each user performs a different initial set of operations. After the standard operations are complete each user has a set of additional operations or procedures that may or may not be used to draw out the information required from the scene.

Ducks Unlimited

DU uses a standard image processing procedure for every one of its scenes. For each scene DU has a file with 230 spectral classes. These spectral classes are grouped into informational classes such as wet meadow, shallow marsh, deep marsh, and open water. The grouping is unique for each scene and variable based on the experience of the digital image interpreter, time of year that the data were acquired, precipitation patterns, available ground truth, and many other factors. Because of spectral class confusion, DU's digital image interpreters use their visual interpretation skills to assure that the information group assigned for the pixel agrees with their visual interpretation of the data. For example, shadows, whether cast onto the image from clouds, terrain, or forest, typically have a spectral signature identical to one of the spectral signatures assigned to shallow marsh. Usually the interpreter can visually distinguish a shallow marsh spectral class resulting from shadows and will edit these to a non-wetland class. In DU's work in Alaska and northern regions of Canada, black spruce may frequently be assigned a spectral class that has been assigned to shallow marsh, yet the interpreter can usually visually distinguish black spruce from shallow marsh and edit the black spruce pixels classified as shallow marsh to a forested class.

SRSC

A few preparatory operations can be applied to most satellite scenes regardless of location of the scene's coverage. These include such things as image-to-image registration, post classification georeferencing, and creating vegetation versus nonvegetation masks. The list of preparatory operations increases when the analysis is restricted to a geomorphic region with a consistent land-surface form, vegetative cover, or regional climate.

5. Which of the TM infrared bands, Number 4, 5, or 7, are most important for wetland identification?

   Answer:
   Band 5 has traditionally been considered the single most important band for its capability to discriminate levels of vegetation and soil moisture. However, a combination of bands is needed for wetland detection.

Ducks Unlimited

The capability of Band 5 to detect moisture makes it the most important band for wetland identification. However, a combination of TM Bands 3, 4, and 5 usually is the best combination of bands for wetland detection. If water quality is of interest, Band 3 should be replaced with Band 1. It is possible that Band 1 may also help in separating open water from open water with submerged aquatic vegetation (SAV).

Earth Satellite Corporation

Band 5 (1.55-1.75 μm) has traditionally been considered the single most important for its capability to discriminate levels of vegetation and soil moisture. In Earth Satellite's experience, Band 4 (0.76-0.90 μm) is also important in the classification of vegetative communities and vegetation moisture, from which wetlands may be inferred. Earth Satellite's approach to land cover classification utilizes all six TM reflective bands in order to identify homogeneous classes. Additionally, Earth Satellite utilizes a proprietary program, GEOVUE, to simultaneously analyze multiple bands of data, either in a multispectral or multitemporal fashion, or in combination.

SRSC

In general Band 5 is the most important for wetland identification due to its sensitivity to soil and vegetation moisture. But this is not always the case; it depends on what type of wetland is being classified. For example, Band 5 was most important for identifying standing water and saturated soils associated with farmed wetlands in the Mississippi Delta. Band 4 was most important in identifying patches of healthy natural vegetation located within recently plowed agricultural fields in the Prairie Pothole region of North Dakota. The patches of vegetation are surrogate indicators of temporary wetlands where the potholes were filled with water when the farmer began plowing the field. Because these potholes were filled with water, the farmer simply plowed around the potholes. At the time the satellite scene was acquired the open water in the pothole had evaporated and the natural vegetation now growing in the pothole contrasted both spectrally and spatially with the surrounding bare soil.

NCG

NCG has found that TM Bands 5 and 7 to be extremely useful in differentiating vegetation.

6. How many wetland classes have you been able to successfully discern using satellite data? Can you provide a listing of these classes?

   Wetland classes used in waterfowl habitat and wetland inventory.
   (See Appendix A for categories identified by DU and SRSC)

7. Which wetland classes are the easiest to discern, and which classes are the hardest? Please provide some statistical insight as to relative accuracies.

   Answer:
   Although quantitative statistical data are not available, the consensus is that the easiest classes to discern are permanently flooded or intermittently exposed open water ponds (palustrine unconsolidated bottoms). The difficulty increases moving through the wettest to driest marshes, deciduous forested wetlands, evergreen

forested wetlands, and any type of scrub-shrub wetlands. Mangroves are an exception; due to their unique spectral reflectance, they are the easiest vegetated wetland type to identify. For coastal wetlands the ease and ability depends on tide conditions. With appropriate tide conditions, mangroves are the easiest class to discern, then moving to salt marshes to forested wetlands with scrub-shrubs (other than mangroves) being the hardest class to discern.

<u>Ducks Unlimited</u>

DU's work in the Prairie Pothole region found that shallow marsh, deep marsh, and open water classes are the easiest to discern without any editing. The open water classes are always easy to discern; spectral class confusion has never been a problem with these classes. In general, the deep marsh class is as easy to discern as the open water class; seldom has spectral class confusion been a problem with the deep marsh class. Wetter shallow marsh classes are nearly as easy to discern as the deep marsh classes.

Dry shallow marsh classes frequently have a great deal of spectral class confusion. For these spectral classes, which typically describe the temporary basins or the margins of seasonal or semipermanent wetlands, spectral class confusion is often a problem. Spectral classes which discern temporary wetlands and wetland margins of seasonal and semipermanent wetlands often will cause commission errors, identifying moist areas in fields as wetlands. DU removes these commission errors using its image editing procedures.

For example, E1OW (estuarine subtidal open water), L1OW (lacustrine limnetic open water), and POW (palustrine open water) are spectrally identical and must be edited to these classes based upon location and size of wetland. In a similar manner, emergent vegetation of estuarine, lacustrine, and palustrine systems are spectrally identical and must be separated by an editing or post-processing step.

8. Can you provide the committee with quantitative or qualitative information on wetland identification which is accurately related to wetland size, water regimes, and wetland coverage classes and types?

   a. Wetland size

   Answer:
   The accuracy of satellite data for identifying wetlands is heavily dependent on collecting satellite data when the wetlands are inundated. A multiacre temporary basin that is dry and cultivated when the satellite data are collected usually cannot be identified using satellite data. However, stock ponds (or dugouts) in Montana range land are readily identified using Landsat TM data even though these ponds represent very small areas (10 ft by 20 ft) of open water.

Ducks Unlimited

Using Landsat TM data collected in late May 1986, and employing DU's 1987 image processing procedures, which did not include an interactive editing step, only 22 percent of the wetland basins (identified from NWI data) less than 2 acres in size were classified as wetlands as shown below:

Wetland basin size (acres)	Percent classified by thematic mapper data
0-1.9	22
2-4.9	70
5-9.9	91
10-24.9	96
>25	100

The drought of the 1980's severely impacted the available habitat for waterfowl. By the end of May 1986 most of the temporary basins were dry and many of the seasonal and some of the semipermanent basins were dry. Also during the 1980's, many temporary and seasonal basins were cultivated, making wetland detection very difficult, even using conventional aerial photography techniques.

b. Water regimes

Answer:
In the Prairie Pothole region, satellite data collected in late April or very early May in years of normal precipitation are ideal for delineating wetlands. However, it is difficult to ascertain from spectral information if a wetland has a temporary, seasonal, semipermanent, or permanent water regime. Satellite data collected late in the year provides information on water regimes, but can make wetland detection very difficult.

c. Wetland coverage classes and types (i.e. forested, scrub-shrub, emergent, etc.)

Answer:
DU's biologists, using their habitat inventory products derived from satellite data, have been pleased with the separation of shallow marsh, deep marsh, and open water when using data collected from mid-May to June. When using late April or early May data, deep marsh typically has a spectral signature that is difficult to separate from open water. DU frequently debates the trade-off between using late April or early May data to improve detection of temporary and seasonal wetlands or mid-May to June data to improve separation of wetland types.

SRSC

An important factor in the size question is how much spectral contrast there is between pixels of certain wetland classes and surrounding pixels of other land cover classes. In the Prairie Pothole region of North Dakota SRSC had success in classifying open water, deep marsh and shallow marsh as small as one-half acre in size using SPOT multispectral data. It should be pointed out that SRSC believes wetlands were detected at this size because of optimum conditions: open water was generally surrounded by the bare soil of an agricultural field or much drier prairie grass vegetation which had a significantly different spectral reflectance. The same could be said for the deep marsh and shallow marsh. Since SRSC has only conducted one wetlands study in the Prairie Pothole region, they can not state with certainty that satellite remote sensing is capable of repetitively identifying wetlands at this size. But they are encouraged by these early results and intend to do further wetlands research in this region. The SRSC mapping procedures have not been documented in detail or published in the technical literature where they would be subjected to peer review of the process and map products. Quantitative testing against NWI digital wetland data will be performed on other maps in the Prairie Pothole region.

9. What do you believe is a reliable minimum mapping unit for forested wetlands, scrub-shrub wetlands, open water ponds?

   Answer: No definite answers were provided.

NOAA-C-CAP

Jerry Dobson, of Oak Ridge National Laboratory, reported that on the Salisbury, Maryland 1:100,000 scale USGS quad, his initial analysis only identified 30 percent of the forested wetlands. This accuracy was doubled to 60 percent after some initial field work using a fall satellite scene. Accuracy was further improved to 67 percent through additional field work and the use of a spring scene.

EPA

Ross Lunetta, of EPA, has used a wetland/upland mask developed through the use of satellite information gathered during the leaf-off wet season of a normal year to help identify deciduous forested wetlands in subsequent data gatherings. He has not tried this technique on evergreen forested wetlands. The wet season scene is selected using rainfall data and/or river stage data.

SRSC

SRSC has successfully classified hardwood forested wetlands in the Yazoo basin as small as one acre using TM data. This assumes the use of multiple dates of imagery and acquiring scenes when the hardwoods were inundated with flood water. This does not imply that they can map all forested wetlands down to one acre. Quantitative testing against other wetland mapping efforts have yet to be performed.

Ducks Unlimited

DU has had only minimum experience in delineating scrub-shrub and forested wetlands. From their limited experience, they believe that these features may be two of the most difficult habitat types to accurately delineate using satellite data. These habitats are best identified in leaf-off periods when the soil is fully inundated or saturated. Even under these optimum conditions, blocks of forested and scrub-shrub wetlands smaller than 10 acres cannot be reliably detected.

Earth Satellite Corporation

Earth Satellite Corporation believes that a minimum mapping unit of 5 to 10 acres is possible for detection of forested and shrub-scrub wetlands by digital methods using satellite imagery. This size may be reduced by using additional data sources, GIS data, and/or other visual (monoscopic and/or stereoscopic) data; the presence of spectrally unique wetland forest species in an area, e.g., mangrove, would also help reduce this size.

Emergent wetlands and deep water habitats are detectable to as little as 3-5 acres, depending upon water regime at the time of imagery. Smaller than 3 acres, with current spatial resolutions, the accuracy of classification decreases rapidly.

10. What are the problems associated with identifying narrow bands of wetlands such as those found along tidal creeks or riparian wetlands, which are found along streams and are often very important?

    Answer:
    The drier the adjacent upland the easier it is to identify riparian wetlands. In general the riparian strips need to be at least 60-90 meters wide to be identified. Most riparian specialists believe that a minimum mapping width of 60-90 meter essentially precludes the use of satellite data for mapping many riparian areas.

Ducks Unlimited

DU's work in Alaska found that most narrow drainages have varying widths of sedge, small willows scattered amongst the sedges, or sedges primarily dominated by small willows or small coniferous shrubs. If the linear feature is narrow (90 m wide or less), it can be very difficult to properly classify. Also, many of the drainages have small slow-flowing creeks that are often not delineated by NWI. Drainage without such creeks offer little value for waterfowl except as nesting habitat. However, drainage with slow-flowing creeks have value for waterfowl. Even though these creeks are often not displayed by NWI on their 1:63,360 scale maps, DU's Landsat TM data have enabled the display of these narrow ribbons of water.

One additional problem with delineating narrow linear features using satellite data is the mixed pixel problem. A narrow band of water in a creek surrounded by upland grasses may be erroneously classified as a shallow marsh. In this situation, water may cover one-third of a pixel while upland grasses cover the remaining two-thirds of the pixel. The spectral response for this pixel will be a mixture of water and vegetation, which is identical to the spectral response of shallow marsh.

SPOT

Mapping of a 60-meter wide swath would be possible with SPOT multispectral (3 pixels wide) or with merged panchromatic and multispectral (6 pixels wide), provided these wetlands are not obstructed by upland overstory. If overstory is present and is composed of deciduous trees, imagery can be acquired during the spring wet season, before leaf-out occurs.

SRSC

Using ancillary data such as digital line graph (DLG) hydrography data and digital elevation models (DEM's), a mask can be developed that identifies areas that are a predetermined elevation above the nearest water source. Using this mask the feature space over which spectral analyses are performed can be reduced. A classification can be done on the reduced area, which facilitates delineation of narrow bands of wetlands. Applying this technique along with other techniques should permit the identification of riparian areas less than 90 meters wide using satellite imagery in certain geomorphic regions.

11. Due to the scale of coverage, it has been reported that satellite data consistently underestimate the acreage of individual wetland basins. If this is true, can a conversion factor be determined? Is the underestimation a function of the size of the wetland basin or the scale at which the satellite senses?

    Answer:
    Satellite data consistently underestimate the acreage of individual wetland basins. There is ongoing debate as to whether an expansion factor or factors, can be developed to convert these underestimates.

Ducks Unlimited

Satellite data consistently underestimate the acreage of individual wetland basins because the drier margins of these wetland basins are inaccurately classified as upland habitat. In classification of satellite data the analyst is constantly making trade-offs between omission and commission errors. Commission errors (i.e., identifying a wet area in an upland field as a wetland class) are increased as omission errors (i.e., identifying the dry margin of a wetland as an upland class) are decreased. Typically when grouping spectral data for wetlands, those spectral classes representing dry wetland margins are not assigned as a wetland class. If they were, considerable commission error would occur and nonwetlands (moist areas in fields) would be assigned as wetlands.

Labor intensive techniques can be used, such as DU's image editing procedures to help reduce this problem. In addition, all spectral classes that represent not only wetland margins, but also nonwetland areas, can be identified and wetlands can be allowed to "grow" into these margins.

A conversion factor developed for a Prairie Pothole scene would likely be meaningless in other geographic regions. Conversion factors could possibly be developed for other wetland types in different regions but would be scene-specific due to water conditions at the time of data capture.

Correction factors could possibly be used to correlate the actual acreage of wetlands mapped using aerial photography to satellite-derived wetlands acreage. For a representative sample of wetland basins in the study area, various dependent variables from the satellite data are needed such as area of basin, length of basin perimeter, shape index, and square and cubic transformations of these variables. Using the actual acreage of the wetland basins as the independent variable and using regression analysis techniques, it is possible to ascertain an appropriate regression model to correct the acreage of wetland basins as derived from satellite data.

NCG

NCG believes there are scientifically valid sampling and estimation procedures whereby adjustments can be made to figures generated by 100 percent mapping, but it is not likely that several simple adjustment factors will provide desired reliability.

EPA

Although a conversion factor may aid applications that require only acreage totals over broad areas, it is unlikely that a conversion factor could improve mapping of individual wetland boundaries.

12. Have you had any success in identification of SAV and/or grass flats?

Answer:
No. The satellite can "see" some percentage of the SAV, but no verification studies have been performed. The USGS estimates that using TM data, they have been able to identify approximately 70 percent of the submerged aquatic beds in the tidal Potomac River that can be detected using 1:24,000 scale photographs. Best results are gained when both the satellite imagery and aerial photography are captured at low tide. As with aerial photography, the ability of satellite imagery to identify SAV is heavily influenced by wind conditions, depth, and turbidity. Even small ripples on the water can prevent identification of SAV. Turbidity in the water conceals much such vegetation.

Ducks Unlimited

In some DU study areas in Alaska, spectral classes were identified that had a degree of correlation with areas identified as aquatic beds on the available NWI maps. Also, one of the scenes DU used in Mexico provided data for parts of southern Texas that NWI maps cover; some spectral classes appeared to correlate with L2AB (lacustrine littoral aquatic bed) on the NWI map. DU researchers do not believe that satellite data actually detects the SAV. They believe they are detecting shallow water that could be providing adequate conditions (water depth and light penetration) for the growth of SAV.

Maryland Department of Natural Resources

The Maryland Department of Natural Resources (MD-DNR) delineated and classified SAV using SPOT satellite multispectral digital data (acquisition date of SPOT data, September 27, 1987). The results of the effort are published in a report entitled "Delineation and classification of submerged aquatic vegetation (SAV) using SPOT satellite multispectral digital data." The following is from a report that was written by Dr. K. Peter Lade of Salisbury State University under contract to MD-DNR:

> "Aerial photography has been, to date, the principal data source other than field verification. There is little question that good quality aerial photography, taken under the right circumstances, at the right scale, and supplemented by good field testing, can better serve the purpose of documenting the distribution of SAV than any other data collection method.
>
> Satellite data are, perhaps, the next most obvious data source. Synoptic in its coverage, digital in format, satellite data have the potential of not only automating much of the tedious process of matching "photography" to standard orthographic projections, but has the further advantage of being comparatively inexpensive. The disadvantage is mostly one of resolution.
>
> SAV beds were identified on the SPOT satellite data of September 27, 1987, by displaying segments of the satellite tract on screen for computer aided analysis. In each case, it was assumed that a bed density of less than 25 percent would probably not be visible at the 20 meter resolution of the multispectral satellite data. A screen cursor was used to point at SAV colonies and the computer was permitted to suggest additional locations of submerged aquatic vegetation within the experimental frame.
>
> The effect of this method was to reduce the total estimate of SAV in two ways. First there is the loss of statistics for those beds with low density. Since there is no reliable method for estimating the total contribution of low density beds as a fraction of total acreage for higher density beds, there will inevitably be an error that may account for as much as 10 percent of the potential acreage of SAV in the Chesapeake Bay and tributaries. Second, area calculations were not based on polygons circumscribing an area of identified SAV, but rather on the point distribution of targeted SAV coverage. This resulted in a more nearly accurate

mapping of aerial extent of SAV, as opposed to the representational mapping of previous studies where polygons were circumscribed around observed SAV beds. In this case, the lower acreage figures to be expected through feature mapping of the satellite data would, in fact, be a better estimate of the actual distribution of SAV than the photo-mapping of previous years."

SPOT

The National Park Service has used SPOT multispectral imagery to locate and track the movement of large blooms of SAV, specifically hydrilla, which are causing navigational problems on the Potomac River. SPOT was able to acquire imagery at very specific times, which coincided with low tides and maximum SAV exposure.

SPOT multispectral imagery was used as a rapid and accurate means of making long-term measurements of biomass for monitoring purposes. The imagery allowed for the detection of small changes in vegetation and environmental characteristics. The ability to acquire the imagery at specific times was critical to the study. Spartina alterniflora within the Great Marsh near Lewes, Delaware, was studied to correlate changes in wetlands biomass distribution with precipitation. Three SPOT scenes, approximately one year apart, were digitally compared. A supervised classification was performed to identify those wetland areas dominated by Spartina alterniflora. A vegetation index, based on the relative reflectance values of the Spartina, was then developed and used to automatically map Spartina according to relative density, and thus biomass. This proved to be a highly accurate, nondestructive, and rapid means of assessing and monitoring biomass distribution.

13. Can the 10-meter panchromatic data from SPOT help compensate for the lack of Band 5 (1.55 to 1.75 μm) midinfrared radiance?

Answer:
The 10-meter panchromatic data from SPOT cannot identify wetlands as well as the 30-meter TM data with Band 5. But this is not a fair question because 10-meter panchromatic SPOT data are not a replacement for Landsat Band 5 data. Neither is Landsat Band 5 data a replacement for 10-meter SPOT data. Both make valuable and unique contributions in extracting information about ground cover. They do not replace each other, but are viewed by most users as complementing each other.

TM's midinfrared bands (especially Band 5) have unique capabilities for detecting wetlands. Wetlands that are completely vegetated and not inundated, and dry mud flats are very difficult to classify as wetlands using panchromatic data alone. A combination of visual and near-infrared data, or panchromatic data in combination with visual and near-infrared data are needed. Mapping of a swath at least 60-meters wide would be possible with SPOT multispectral (3 pixels wide) or with merged panchromatic and multispectral (6 pixels wide), provided these wetlands are not obstructed by upland overstory. If overstory is present and is composed of deciduous trees, imagery can be acquired during the spring wet season, before leaf-out occurs. If mid-infrared data were available at 10-meter resolution, SPOT would have a very powerful tool for wetland detection.

Ducks Unlimited

DU has successfully combined 10-meter panchromatic data from SPOT with TM data (including Band 5). They believe that spectral classifications using combined data provided little improvement over using TM data alone. The visual enhancement of data allowed DU's digital image interpreters to slightly improve their editing decision. For this technique, DU used TM Bands 3, 4, and 5, and a hue, saturation, and intensity transformation. The result of this transformation was a three band file. One band depicted values for hue, the second band depicted values for saturation, and the third band depicted values for intensity. The intensity band was replaced by the values from the panchromatic band. Using a reverse transformation, the hue, saturation and intensity files were transformed to a 3-band file representing red, green, and blue. This 3-band file was used for the classification procedure.

SRSC

SRSC has developed a proprietary method of merging SPOT panchromatic data with SPOT multispectral data. Unlike some of the traditional merging techniques (i.e. intensity hue saturation transformation) SRSC's method of data integration does not significantly change the original digital number (DN) values of the SPOT multispectral data. This method reportedly gives their analysis the best of both worlds by producing a data product that has the improved spatial resolution of the panchromatic data and retaining the spectral resolution of the SPOT multispectral data. SRSC is in the process of classifying wetlands in the Prairie Pothole region of North Dakota. Early results have indicated that the merged product has identified open water ponds, deep marshes, and shallow marshes as small as between one-quarter and one-half acre. Many of these small wetlands were not classified when analyzing SPOT multispectral data (20-meter resolution) over these same areas. SRSC believes that for this unique geomorphic region, the SPOT panchromatic data merged with the SPOT multispectral data using SRSC method may compensate for the lack of a middle infrared band because of its improved spatial resolution. SRSC plans to conduct more research with the merged data in this region and will determine if classification of potholes is improved significantly over classification with SPOT multispectral data. Quantitative testing against NWI digital wetland data will be performed.

14. Have you had any success in using stereo data from SPOT to increase your accuracy in wetland identification, classification, and delineation?

    Answer: No experience at all.
    Theoretically, if stereo air photos were not available for a desired time period and suitable SPOT stereo pairs were available, they could be used in film or print

form, or in digital form in a digital stereoplotter workstation to provide stereo data.

15. Can a satellite be reprogrammed in flight so as to capture data for different purposes?

Answer:
The SPOT satellite viewing angles can be reprogrammed to acquire imagery. The viewing angles can be adjusted as much as 27° on either side of nadir (54° angle of adjustment) to acquire imagery anywhere within a 1000 km swath.

SPOT

The uniqueness and strength of the SPOT satellite system is based partially on the capability to program the satellite upon request. A conterminous U.S. acquisition request must be received one week prior to the start date. A programming request must be received three weeks prior to the start date for Alaska and Hawaii.

Specific project requests can be accommodated with only one day notice to program the satellite (e.g. to monitor flood waters and capture a scene at highest flood level to update the one-hundred-year flood plain).

The SPOT satellite has two high-resolution visible sensors (HRV's) enabling programming of a twin pass. A twin pass can provide coverage of 117 kilometers (two scenes overlap). The HRV's can be programmed to acquire a scene within a $\pm$ 27° swath. The ability to program the satellite enables SPOT to capture a particular point on the earth three times a week.

EOSAT

Landsats 4 and 5 have fixed data streams; the 85-megabit-per-second seven-band TM data and the 15-megabit-per-second four-band multispectral scanner data. EOSAT believes there is no ability to reprogram for different purposes.

EOSAT transmits two days of commands to each satellite every day. The commands for the second day are made as insurance against loss of transmission capability. EOSAT experiences extremely few such losses. The command loads include the start and stop transmission times for transmitting all seven bands to all ground stations.

Inclination adjustments necessary to maintain the satellite over the Landsat world reference system paths need to be performed less than once per year. Orbit adjustments for altitude correction are performed during satellite nighttime orbit without interrupting service to the ground stations. EOSAT does not acquire data during periods of orbit adjustment or when they are outgassing the cold focal plane (about once every four months).

16. Is georeferencing now sophisticated enough to allow for a pixel by pixel analysis in order to perform change detection?

Answer:
Yes, but with some qualifications. Relative positional accuracy of a geocoded satellite image is a function of spatial resolution (pixel size), the quality and accuracy of the paper maps used for ground control points, the global positioning system (GPS) setup if used (differential GPS is the most accurate), the skill of the image analyst, and the quality and appropriateness of the computer algorithms used to process the data. It is easier to get high accuracy for flatter, well surveyed areas, although a properly orthocorrected image can be highly accurate. In general, root mean square (RMS) errors can be as low as 0.5-1 pixel (5-10 meters for SPOT panchromatic, 10-20 meters for multispectral) for most U.S. areas. When SPOT reports error(s) on a product, it usually is referring to the specification, which indicates the greatest error allowable. In the case of SPOTView 7.5-minute quadrangles, which are panchromatic data orthocorrected using 7.5-minute quadrangles digital elevation models, the error specification is 15 meters, or 1.5 pixels.

<u>EOSAT</u>

EOSAT provides map-oriented precision-corrected imagery which is accurate to within $\pm$ 15 meters (one standard deviation) with respect to a map, exclusive to terrain effects. Within a scene, the pixel-to-pixel distances are accurate to less than one meter, also exclusive of terrain effects. Many users perform change detection using two such scenes.

If elevation effects are important, EOSAT can provide map-oriented terrain-corrected data, which is corrected using control points from maps and digital elevation maps. The algorithms used in correcting Landsat data are designed to the specification of plus-or-minus one-third pixel for scene-to-scene registration. These specifications are for the entire scene; they are not random errors at each pixel within a scene.

<u>Ducks Unlimited</u>

DU typically registers full scenes of TM data to the Universal Transverse Mercator (UTM) grid system using 20 to 30 control points and a linear transformation. For regions where accurate UTM coordinates for the control points are available from published maps or using a GPS, DU can obtain RMS errors of less than 30 meters. (Obtaining UTM coordinates for control points in Mexico using the 1:50,000-scale map sheets results in a RMS error of 40 to 45 meters.) For example, using these techniques in the U.S. and Canada, DU would register two different scenes to the UTM grid system, and the overlay of these two images would not be a perfect fit.

Pixel-to-pixel registration is not required to identify wetland change. Registration of pixel-to-pixel or its near neighbor is readily achieved in the simple georeference procedures used by DU. In its wetland change detection procedures, by using connective components techniques, DU identifies all pixels from either scene that are connected to the wetland basin. For example, a small temporary basin may have 4 pixels of shallow marsh in one scene and four pixels of shallow marsh in the other scene, but because of project rating error, only two of these pixels are identified as shallow marsh in both scenes (see figure 1).

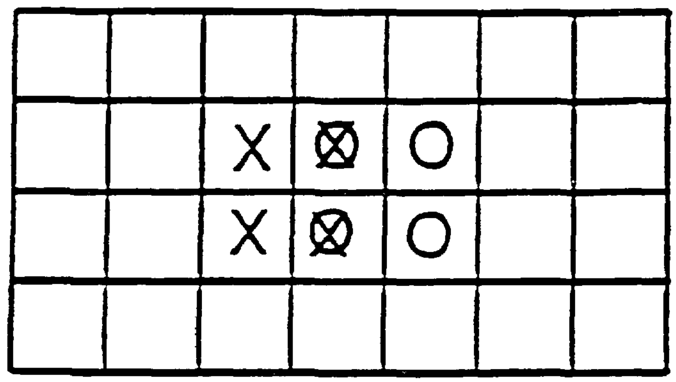

Figure 1. An example of project rating error, where a small area is not registered perfectly in all imagery. (Each box represents one pixel; X, small area in one scene; O, same small area in comparison scene.)

Another procedure is similar to the procedure DU is using, but replaces the linear transformation with a high-order polynomial transformation. The number of control points required is dependent upon the order of the polynomial transformation used. DU is not using the polynomial transformation but believes that when 100 or more of its control points are collected and a third or fourth order polynomial is used, pixel-to-pixel registration can be obtained.

Using connective components techniques, the basin in figure 1 would be identified as a six-pixel basin. In the first year, four pixels are wet and two pixels are dry. In the comparison year, the same four pixels are wet and two are dry. Consequently, no change has occurred in the wetland. Even if small change is reported because of registration errors or classification errors, only those basins exceeding a threshold of change would be classified as changed basins.

<u>Earth Satellite Corporation</u>

For imagery acquired over the U.S., using the most recent USGS 1:24,000-scale topographic quadrangles, image georeferencing RMS errors can be often less than one-half pixel (5 to 15-meters, depending upon image source). Earth Satellite Corporation routinely georeferences imagery to subpixel accuracies. Earth Satellite's standard procedure in change detection activities is to georeference the first image to the best available map source, then to register the second image to the first via image-to-image correction. This minimizes displacement to as little as one-half pixel between the image dates. Theoretically, a pixel-by-pixel analysis could be conducted; in reality, one would expect to encounter edge differences of up to one-half pixel on unchanged parcels between image dates.

To avoid numerical problems with the polynomial approach and remove the dominant error source, ephemeris error, along with smaller errors such as clock error, attitude bias, and spacecraft-instrument misalignment bias, the Earth Satellite Corporation uses the following procedure:

- Perform a systematic geometric correction on a single band (usually Band 4).

- Use USGS (or customer-supplied, non-U.S.) maps to identify control points within the scene.

- Given the error in location of the control points from their correct position, determine the errors in the ephemeris of the spacecraft.

- Correct the ephemeris error and regenerate the geometric correction model coefficients.

SRSC

As the first step in the georeferencing process, SRSC generally performs image-to-image registration. One image is chosen as the base and the remaining images are registered to that base. This is different from georeferencing each scene to a base map, where a half-pixel error in one scene and a half-pixel error in another scene could potentially result in a composite error of one pixel, which can be significant when doing change detection. By performing image-to-image registration, any error that occurs during the georeferencing process is consistent for all the images since they all now overlay each other and the same georeferencing equation is used for all scenes.

Secondly, SRSC georeferences data using a nearest neighbor resampling routine after the raw data has been classified. Georeferencing after the classification ensures that pixel values have not been altered to such a degree that small areas and borders cannot be correctly classified. But even when using a nearest neighbor resampling routine, SRSC's analysts check the georeferenced classified image against the nongeoreferenced classified image to check for potential alterations produced by the georeference transformation.

NCG

NCG has rectified SPOT and TM data to an RMS error of 0.7 pixels or less using three or four ground control points per quad, classified respective scenes, performed change detection on as many as four scenes over the same area, and experienced no known registration related problems. Film-based orthophotoquads are preferred for picking ground control points. Ground registration is the most time consuming step in processing satellite data because of the amount of time required to select ground control points.

17. How do you navigate on the ground to locate and identify 1 to 6 or more pixels depicting change?

Answer:
Identifying the precise location of one to six pixels on the ground can be very difficult. Pixels adjacent to readily identifiable fixed features (such as the intersection of section lines) can be readily identified. However, trying to use the shape of a wetland on the ground to identify a particular pixel is difficult and can lead to errors. The wet border of wetland can rapidly change from week to week and certainly changes seasonally and annually. Such borders are not usable to identify a particular pixel on the ground.

Ducks Unlimited

Use of the GPS offers a potential for pixel identification on the ground. One of DU's employees using the GPS in Alaska felt that he could indeed identify the location of individual pixels. Other employees used a GPS in Mexico and felt that they could not rely on the GPS to identify the location of individual pixels. In Mexico, DU employees identified various road intersections and obtained the UTM coordinates for the road intersections using the GPS. They also obtained the UTM coordinates for the same road intersections from various published map sheets at a scale of 1:50,000. Differences between the UTM coordinates obtained from a Mexican map and from the GPS ranged from 26 meters to over 1200 meters. Using the GPS in Alaska, it only took a few minutes to obtain the UTM coordinates. In Mexico, employees frequently waited 15 minutes or longer before data from three GPS satellites were obtained. The longest wait before obtaining data from three GPS satellites occurred early in the mornings and late in the afternoons. The signals from the GPS satellites may have been degraded by the U.S. Department of Defense when DU was in Mexico. By using two GPS receivers, one located on a benchmark, it should be possible to determine the location of pixels on the ground.

Earth Satellite Corporation

Earth Satellite Corporation has successfully identified change polygons using georeferenced imagery. Pixel column and row locations of a wetland polygon centroid are translated into their UTM or latitude and longitude coordinates. Using GPS receivers and maps and imagery for corollary reference, it is then possible to locate the pixels on the ground within the accuracy of the GPS receiver. In the case of curvilinear or oddly shaped wetlands, where the centroid falls outside the polygon, a GIS editing step would be used to move the coordinate inside the polygon. This GIS edit step could also select any particular points or clusters that are of specific interest to the analyst from visual examination.

18. How is NWI digital data processed so that they can be interfaced with TM digital data used by DU, and is this process done on a unique basis or a routine basis?

Answer:
DU has interfaced NWI digital data with satellite data in two ways. For primarily visual comparisons, DU overlays the NWI vector data directly onto its raster data. These types of overlays of vector data onto raster data are less than ideal when using a monitor on which one raster cell is presented as one pixel on the monitor. Using these techniques, the NWI vectors totally obscure the raster data of small wetlands. Using a plotter, however, each raster cell of the satellite data can be represented by a 2 by 2, 3 by 3, 4 by 4, or greater block of plotter pixels. The NWI vector lines only require a single plotter pixel. Therefore, fewer of the cells from the raster satellite data will be obscured by the NWI vectors.

For analytical work, DU converts NWI data to raster format at the same resolution as its raster satellite data. Using NWI data as fact, DU determines the maximum extent of each wetland basin. For each wetland basin, DU measures the acreage of various NWI wetland types and the acreage of wetland types derived from satellite data. These data are maintained in a wetland basin data base. By using both the NWI data and the satellite-derived wetland information, DU can better evaluate the wetland as waterfowl habitat. As an example, two hypothetical basins of the same size might be reported by NWI as 100 percent PEMC (palustrine, emergent, seasonally flooded). For basin A, DU's satellite data recorded 60 percent of the basin as shallow marsh and 40 percent of the basin as deep marsh. For basin B, DU's satellite data reported 60 percent of the basin as shallow marsh and 40 percent as nonwetland. Basin A, at the time that the satellite data were collected, was providing better waterfowl habitat than basin B.

SPOT's smaller pixel size for 20-meter multispectral data would help to alleviate the problem that DU reported when overlaying vector data over raster data. A one-pixel wetland area interpreted from Landsat TM 30-meter data would most likely occupy from two to four pixels with SPOT 20-meter data. A rasterized polygon boundary (from vector data) of one-pixel SPOT 20-meter data would no longer obscure an entire one-pixel TM 30-meter wetland.

A merged and properly georeferenced data set incorporating SPOT panchromatic (10-meter) with Landsat TM (30-meter) data would allow for easier and more accurate registration of satellite data with the NWI vector data base, due to the enhanced geometric fidelity of the satellite data.

Maryland Department of Natural Resources

In April 1989, the State of Maryland enacted the Nontidal Wetlands Protection Act. This law established a program to prevent net losses of nontidal wetlands. One of the program's first requirements was creation of new maps showing nontidal wetlands and relating them to identifiable ground features. The maps also needed to show areas that were designated as Wetlands of Special State Concern that contain rare, threatened, or endangered species, or that have unique habitat value. In December 1989, the MD-DNR completed a project using SPOT panchromatic imagery as a georeferenced base and overlaid it with NWI digital wetlands data.

It was not possible to create a series of orthophoto base maps for the State in this period of time. It would have been inappropriate to use uncorrected aerial photography. SPOT 10-meter panchromatic data provided imagery in time to meet project deadlines and at a lower cost than aerial photography. SPOT imagery can be printed at 1:24,000 scale and provides ground resolutions that allow the average person to orient themselves on the ground and identify features with which they are familiar.

The full scenes provided by SPOT were reformatted to match the USGS 7.5-minute topographic quadrangle series for Maryland. This process involved extraction of the individual quad images, rotation to true north, and registration to existing map vector data sets. Where the overlap between scenes was not great enough to allow extraction of a full 7.5-minute quad from one scene, portions of two or three scenes were extracted and merged to create one 7.5-minute base map. The NWI data files, as well as files of the transportation network, hydrology, and place names were procured in 7.5-minute quadrangle format. These data layers were plotted into the image raster and then converted to a print file that could be used for on-demand printing of paper maps using an electrostatic printer.

This work was a one-time effort that provided the basis for a turn-key GIS that is currently in use for project review and planning purposes.

19. Do you agree with the following statement made by Dr. Gregory T. Koeln, Director of DU's Habitat Inventory Program?

    "Satellite data are best used as a monitoring tool for wetlands and are a poor tool for establishing baseline data on wetlands. Combining NWI digital data with satellite data provides much greater information than either product used alone."

    Answer:
    Most people would agree in general with Dr. Koeln's statement.

Ducks Unlimited

Dr. Koeln replied "Yes, but I wish I had better stated my point. I am not certain of the source of the above statement, but I have expressed the sentiment of this statement many times. Perhaps I can better describe my views thus:

> 'Current satellite capabilities are best used for monitoring wetlands and evaluating selective functions of wetlands (i.e., evaluating waterfowl habitat). As a monitoring and evaluation tool of wetlands functions, satellite data are best used in conjunction with NWI digital data. Combining NWI digital data with satellite

data for evaluating wetland functions provides much greater information than either product used alone. Current satellite technology cannot delineate and describe wetland types as accurately as the procedures used by NWI. Where NWI data does not exist, the currently available satellite technology <u>should</u> <u>not</u> be used if the objective is wetland delineation. However, if the objective is to evaluate wetland functions at a point in time (i.e., available waterfowl habitat at the time the data were collected), current satellite technology offers an economically feasible solution for rapidly appraising selected wetland functions.'"

<u>SRSC</u>

SRSC's biggest objection to Dr. Koeln's statement deals with his comment that satellite data "is a poor tool for establishing baseline data on wetlands." SRSC kindly disagrees with this statement, because the SCS is now using SRSC's wetland classifications for the States of Mississippi and Arkansas as their wetland base for administering the 1990 Farm Bill. Also, their preliminary work in North Dakota demonstrated the possibility that satellite data could be used to establish a wetland base, especially in the agricultural prairie areas where wetlands have not been inventoried. SRSC cannot yet provide any statistical insight into the comparison of their mapping efforts with those of NWI, but they believe their wetland mapping compares favorably with the NWI effort in the SRSC study area in North Dakota. They also believe that satellite data are a useful tool for monitoring change in wetlands because they have done this work for the SCS to identify converted wetlands. The idea of integrating satellite data with NWI data is appealing because the NWI would serve as an excellent mask to locate wetlands prior to processing the satellite data.

20. At what point can we expect to have permanent storage capability so as to maintain captured digital data on an indefinite basis?

    Answer:
    CD-ROM technology offers the greatest potential for maintaining near-permanent storage of digital data.

    Until there is a storage media capable of lasting a human lifetime or longer, there will always be a need to perform archive maintenance. EDC has a project to copy the Landsat 4 and 5 archive to a helical scan magnetic tape. This activity will begin in October 1992. The computer system is now being built to perform this activity.

    EOSAT will be working with EDC personnel in this project and expect to initiate a similar project for EOSAT's own data in the near future. Landsat 4 and 5 data will be available from 1982 to present.

    There have been recent advances in recording media. There is now an optical tape that has a very long predicted shelf life. It is in use at Landsat's Canadian receiving station and is about to be installed in the European Space Agency facilities.

The tradeoffs usually considered in archive media are long term costs and retrieval speed. At the moment, tradeoff studies are making EOSAT lean toward helical scan tape recording.

EDC

EDC believes the issue is not the existence of near-permanent storage media, but rather media with a moderate lifetime (e.g. 10-20 years) from which data can be rapidly and cheaply transcribed to the next generation of storage media, and for which hardware necessary for the transcription can be readily available. EDC expects that no matter what media are chosen today for archive storage, a new, more desirable media will be available in 10-20 years, and it will want to then convert to that media. EDC's biggest problem with the existing Landsat archive has not been media performance, but rather the fact that very specialized hardware was required to transcribe the data and, in the case of the older Wide-Band Video tapes, the hardware system is no longer functional.

EDC hopes to have converted all Landsat 1 through 5 data to helical scan magnetic tape within the next five years. Once that is accomplished, subsequent transcriptions will be easier, as the new media will greatly reduce the volume of the data and increase the speed with which the data can be transcribed.

SPOT

SPOT is now implementing an archiving program that uses CD-ROM. A study is currently underway at SPOT that will likely result in an in-house capability to deliver products on CD-ROM later this year. Already several projects on CD-ROM have been delivered to clients, using outside vendors to convert the data to CD.

21. Data Quality Concerns

Ducks Unlimited

DU returned the EOSAT TM tape they had received on December 7, 1991. The scene was returned because of numerous line drops and extensive salt-and-peppering. The replacement tape had not been received by DU as of January 14, 1992.

DU typically receives a product from EOSAT 6 to 8 weeks after the order is placed. DU is greatly concerned over scenes received with line drops or salt-and-pepper data gaps. Rather than return nearly every scene recently purchased, they have found it more efficient to correct these problems in-house. When an unacceptable TM tape is immediately returned to EOSAT for replacement, the replacement typically takes longer to receive than did the original order. DU has waited nearly a year for some of its replacement scenes, and often the replacement scene had numerous line drops and salt-and-pepper data gaps. Fortunately, the data gaps in the first delivery did not occur at the same location as the data gaps in the replacement, and DU was able to patch an acceptable scene together.

DU returned many of the scenes that it had purchased from 1984 through 1986 because of data gaps. EOSAT always provided a replacement and after one or more replacements, DU was usually able to create a complete image. From 1987 through 1989, DU returned few if any scenes, thinking this problem had been resolved. In 1990, however, these data gaps started to occur again.

EPA

Ross Lunetta, at EPA, reported he had similar problems and told the group he did not plan to purchase any TM data until it was available from Landsat 6. He thought the data problem was with the satellite itself. Dr. David Fischel, Chief Scientist for EOSAT, responded that the problem was not with the satellite, but with the processing unit.

EOSAT

The EOSAT computer system in use until October 1, 1991, was the original system built in 1982. Many of the problems associated with the bad data were caused by this aging equipment. The salt-and-pepper effect was principally caused by a deteriorating array processor. EOSAT has experienced a dramatic decrease in rejects since October 1, 1991. In the new system, EOSAT is able to perform considerably more quality assurance checks to catch bad data before it goes to the customer, but EOSAT is still shaking out some insidious bugs. The following problems remain:

- Dropped scan lines (about 16 output image lines), which can occur for scans that are acquired with the antenna looking close to the horizon. Some salt-and-pepper also occurs with low antenna angle.

- Dropped "minor frames" (16 lines high and 16 to 32 pixels long), which are usually caused by tape aging.

The TM tape DU received from EOSAT on December 7, 1991, was produced during the turnover to the new system. Just before EOSAT turned the new system on, the old system failed. The data set that took so long to process was on a particularly obstreperous tape. EOSAT occasionally comes across a tape that is very difficult to read correctly.

REFERENCE

1. Cowardin, Lewis M., and others, 1979, Classification of wetlands and deepwater habitats of the United States: Washington, D.C., U.S. Government Printing Office.

Appendix A

Wetland Classes Used in Waterfowl Habitat and Wetland Inventory

Ducks Unlimited

Listed below are the wetland classes that DU uses in its waterfowl habitat inventory work in the Prairie Pothole region of Canada and the United States. These classes cannot be separated strictly by their spectral characteristics. DU uses ancillary data and visual interpretation of the data using their software system, DISP/TRAIN/EDIT. For example, mud flats may be confused spectrally with various other types of bare soil; however, using visual interpretation skills and the DISP/TRAIN/EDIT software, skilled image interpreters can delineate bare soil categories adjacent to wetlands or occurring on known wetland areas (from ancillary data) as mud flats.

WETLAND CODE	DESCRIPTION
Wetland	
100	Undetermined Wetland
110	Open Fresh Water
111	Open Saline Water
112	Open Turbid Water
120	Deep Marsh
130	Shallow Marsh
140	Wet Meadow
150	Mud Flat
160	Dry Wetland
170	Forested Wetland
180	Riverine Water
Bogs	
200	Undetermined Bog
210	Open Bog
220	Treed Bog

In the last six months, DU began a waterfowl habitat inventory program in Alaska. They currently try to use the following wetland cover classes, a simplification from Cowardin and others (1979):

WETLAND CODE	DESCRIPTION
E1AB	Estuarine Subtidal Aquatic Bed
E1OW	Estuarine Subtidal Open Water
E2EM	Estuarine Intertidal Emergent

DU wetland cover classes for waterfowl habitat inventory program in Alaska (continued)

WETLAND CODE	DESCRIPTION
E2FL	Estuarine Intertidal Flats
L1OW	Lacustrine Limnetic Open Water
L2AB	Lacustrine Littoral Aquatic Bed
L2FL	Lacustrine Littoral Flats
PAB	Palustrine Aquatic Bed
PEMFL	Palustrine Emergent-Flat
POW	Palustrine Open Water
PUBX	Palustrine Unconsolidated Bottom Excavated
R	Riverine
RX	Riverine Excavated
UPAGR	Upland Agriculture
UPBAR	Upland Barren
UPDEV	Upland Developed
UPRAN	Upland Range
UPSS	Upland Scrub-Shrub

SRSC

Listed below are the wetland classes used by SRSC.

Delta Region of Mississippi and Arkansas

Farmed Wetlands
Natural Wetlands
Converted Wetlands
Prior Converted Wetlands

Prairie Pothole region of North Dakota

Open Water
Deep Marsh
Shallow Marsh
Shallow Marsh (located in buffer zone from open water)
Vegetated Potholes (natural vegetation patches surrounded by bare soil of an agricultural field)

Coastal Plain of South Carolina

Palustrine Emergent
Palustrine Woody

SPOT Image Product Fee Schedule

When comparing the price lists for SPOT and EOSAT data it is important to realize that a full SPOT scene covers approximately one-eighth the area of a full Landsat scene.

SPOT Product Fee Schedule

Effective March, 1992

1. Standard SPOT Products

		Panchromatic/Multispectral
Computer Compatible Tapes (CCT)	*Level 1A, 1B* (Full Scene) 6250 or 1600 bpi	$2,450
Film (30% discount w/corresponding CCT)	*Level 1A, 1B* 1:400,000 (Full Scene) 1:200,000 (Full Scene) 1:200,000 (1/4 Scene) 1:100,000 (1/4 Scene)	 $1,800 $1,800 $1,800 $1,800
Photographic Prints	When ordered alone When ordered with corresponding Level 1 CCT or film	$950 $300

2. SPOTView™ – GIS related products

	Digital	Photographic Print
7.5 – (corresponds to USGS 7.5 minute map series) P – Panchromatic XS – Multispectral	$950	$950 (1:24,000 7.5 XS not available)
15 – Four 7.5 minute SPOTViews creating 15 x 15 minute area P – Panchromatic XS – Multispectral	$2,000	$2,000 (1:50,000 or 1:63,360)
FS – Full SPOT scene (37 x 37 miles) P – Panchromatic XS – Multispectral	$3,000	$3,000 (1:100,000)

3. Other SPOT Products

	Digital	Photographic Film/Print
SPOT Digital Terrain Model (DTM) (60%-100% of full scene size/ minimum of 820 sq. mi.) SPOT Quarter scene DTM	$15,000 $10,000	
SPOT BasinView™ - complete coverage of any geologic basin in the world B/W only	$1.80/sq. mi. minimum 2,500 sq. mi.	

4. Almaz Radar Image Products

Standard Product – Approx. 1:100,000 scale photographic print – mosaic of 6 image strips covering 40 x 40 km area	$1,600 each
Specialty Products –	
Level A CCT } 1600 bpi density	$1,600 each
Level B CCT } 6250 bpi density	$2,400
Level C CCT	$2,800
9" x 9" negative of level B Almaz image	$2,400
9" x 9" negative of level C Almaz image	$2,800

5. Promotional Products

Promotional Data Sets	Digital	Photographic
SPOT Education and Evaluation Data Set (S.E.E.D.S.) (33 subscene set)	$900	$ 90 (slides)
SPOT Art™		$300 (unmounted) $400 (mounted)
SPOT Posters		$25 (in mailing tube)

SPOT User's Handbook (3 volumes) – $150

6. Satellite Acquisition Programming

	Standard	High Priority
Programming Fee (does not include final product price)	$600/scene	$2,000+ $300/attempt (up to 10 attempts)

Fees DO NOT include Shipping.
All licensed SPOT Data will be delivered "FOB SPOT Image Corporation," (Reston, VA).
Scene shifting for all standard products included at no charge.
Call for information on duplicate copy prices, rush services, processing options, photographic scales and non-standard products.

Additional information can be found in the document *SPOT Products and Services*.
***Please note:* All prices subject to change without notice.**

SPOT Image Corporation
1897 Preston White Drive Reston, Virginia 22091-4368
(703) 620-2200 • Fax (703) 648-1813

Appendix C

EOSAT Product Fee Schedule

When comparing the price lists for SPOT and EOSAT data it is important to realize that a full SPOT scene covers approximately one-eighth the area of a full Landsat scene.

PRODUCTS PRICE SHEET

(Effective October 1, 1991)

EOSAT® Earth Observation Satellite Company • 4300 Forbes Boulevard • Lanham, MD 20706-9954

DIGITAL PRODUCTS MAP ORIENTED

	Product Code	Price	Copy†
Full Scene - *Terrain Corrected*			
6250 Bpi CCT	TMTT6F	$5950	$90
8mm Cartridge	TMT8NF	5950	90
Full Scene - *Precision Corrected*			
6250 Bpi CCT	TMPT6F	$5500	$90
8mm Cartridge	TMP8NF	5500	90
Full Scene - *System Corrected*			
6250 Bpi CCT	TMST6F	$4400	$90
8mm Cartridge	TMS8NF	4400	90
Subscene (100 km X 100 km) - *Terrain Corrected*			
6250 Bpi CCT	TMTT6Q	$4650	$90
1600 Bpi CCT	TMTT1Q	5115	90
8mm Cartridge	TMT8NQ	4650	90
Subscene (100 km X 100 km) - *Precision Corrected*			
6250 Bpi CCT	TMPT6Q	$4200	$90
1600 Bpi CCT	TMPT1Q	4620	90
8mm Cartridge	TMP8NQ	4200	90
Subscene (100 km X 100 km) - *System Corrected*			
6250 Bpi CCT	TMST6Q	$3100	$90
1600 Bpi CCT	TMST1Q	3410	90
8mm Cartridge	TMS8NQ	3100	90
Map Sheet - *Terrain Corrected*			
6250 Bpi CCT	TMTT6M	$4050	$90
1600 Bpi CCT	TMTT1M	4455	90
8mm Cartridge	TMT8NM	4050	90
Map Sheet - *Precision Corrected*			
6250 Bpi CCT	TMPT6M	$3600	$90
1600 Bpi CCT	TMPT1M	3960	90
8mm Cartridge	TMP8NM	3600	90
Map Sheet - *System Corrected*			
6250 Bpi CCT	TMST6M	$2500	$90
1600 Bpi CCT	TMST1M	2750	90
8mm Cartridge	TMS8NM	2500	90

DIGITAL PRODUCTS PATH ORIENTED

	Product Code	Price	Copy†
Full Scene - *System Corrected*			
6250 Bpi CCT	TPST6F	$4400	$90
1600 Bpi CCT	TPST1F	$4840	90
8mm Cartridge	TPS8NF	4400	90
Subscene (100 km X 100 km) - *System Corrected*			
6250 Bpi CCT	TPST6Q	$3100	$90
1600 Bpi CCT	TPST1Q	3410	90
8mm Cartridge	TPS8NQ	3100	90

PHOTO PRODUCTS MAP ORIENTED

Color Film Subscene (100 km X 100 km) - *System Corrected*		
1:500,000 Positive and Negative Transparencies	TMSCTQ	$2700
1:500,000 Print	TMSC1Q	200*
1:250,000 Print	TMSC2Q	200*
1:100,000 Print	TMSC5Q	200*

* Must purchase Transparency first

PHOTO PRODUCTS PATH ORIENTED

Color Film Full Scene - *System Corrected*		
1:1,000,000 Positive and Negative Transparencies	TPSCTF	$2700
1:1,000,000 Print	TPSC1F	200*
1:500,000 Print	TPSC2F	200*
1:250,000 Print	TPSC4F	200*

* Must purchase Transparency first

MULTI SPECTRAL SCANNER (MSS) PRODUCTS
ORBIT-PATH ORIENTED, SYSTEM CORRECTED ONLY, FULL SCENE ONLY

DIGITAL				
6250 Bpi	(Please specify BSQ or BIL)	MPST6F	$1,000	$90
1600 Bpi	(Please specify BSQ or BIL)	MPST1F	1,000	90
PHOTOGRAPHIC PRODUCTS				
1:1,000,000 Color Positive Transparency		MPSCTF	$600	$120
1:250,000 Color Print		MPSC4F	1,000	200
1:1,000,000 B/W Positive Transparency		MPSBTF	155	31
1:1,000,000 B/W Negative Transparency		MPSBNF	175	35
1:1,000,000 B/W Print		MPSB1F	95	19

NOTE: The prices listed above for MSS products apply to data acquired within 24 months of the date an order is received. For price quotations derived from older MSS data, contact EOSAT Customer Services.

† Copy price applies when ordered with original product.
All prices are represented in U.S. Dollars.

revised 3-5-93

EOSAT'S PRODUCT LINE DEFINITIONS

With the introduction of the new image processing system on October 1, EOSAT changed its product codes and its product descriptions to better reflect the system's capability. The product catalog uses the new names; the box highlights the major changes. The terms are explained further below.

OLD	NEW
Standard	Path Oriented, System Corrected
Geocoded	Map Oriented, Precision Corrected
Movable Scene	Floating Scene
Quarter Scene or Quadrant Scene (100 X 85km)	Subscene (100 X 100km)

Names have been chosen to encourage customers to tailor their orders to their individual needs. *Every order is a custom order*. The phrase "non-standard product" has been banished; if EOSAT can produce the requested item, the order will be filled. The more popular products are listed on the current price sheets available from Customer Services.

Scenes, Subscenes—Digital TM products are available as full scenes, subscenes and map sheets. TM photo products are available as full scenes and subscenes, and MSS products are sold as full scenes.

Floating scenes—Scenes crossing row boundaries are floating scenes, identified by row numbers with decimals. Path 34/row 34.2 begins 20% below the top of path 34/row 34. Except for MSS photographic products, a customer may order data from any area within a path.

Imagery orientation—Landsat products are correlated to the Earth's surface in one of two ways:

Path-oriented products have the spacecraft's orbital orientation, with north off to one side of the image. The category includes what used to be called the standard digital product.

Map-oriented products are usually north up. This adjustment facilitates co-registration of Landsat imagery with other digital data, as in a geographic information system. The customer can select pixel size, map projection and Earth ellipsoid model.

Data corrections—Three levels of Landsat data correction are available.

System-corrected—All products, digital and photographic, are radiometrically and geometrically corrected. Radiometric corrections are made within a band so that a given detector value always represents the same radiance level for the scene. Geometric corrections reorient the image data to compensate for the Earth's rotation and variations in spacecraft position and altitude. Landsat data has always been system corrected.

- **TM Map Oriented Digital Products can be geometric adjusted to two additional levels of positional accuracy.**

Precision-corrected data incorporates ground control points such as road intersections to relate the spacecraft's predicted position to its actual geodetic position. This kind of data used to be called geocoded data. EOSAT has ground control points for areas within the United States. Customers must furnish topographic maps of 1:50,000 scale or better for all other areas. Maps will be returned.

Terrain-corrected data eliminates the distortion that results from recording a three-dimensional view in two dimensions by including relief adjustments from a digital elevation model; this kind of correction is especially helpful if the height difference across a scene is more than 500 feet. EOSAT has models for areas within the United States. For other areas of the world, customers must supply digital terrain model.

January 1993

Acronyms

C-CAP	Coast Watch Change Analysis Program, NOAA
DEM	digital elevation model
DLG	digital line graph
DN	digital number
DU	Ducks Unlimited
EDC	EROS Data Center, USGS
EOSAT	Earth Observation Satellite Company
EPA	U.S. Environmental Protection Agency
EROS	Earth Resources Observation Systems
FGDC	Federal Geographic Data Committee
FWS	U.S. Fish and Wildlife Service, U.S. Department of the Interior
GIS	geographic information system
GPS	global positioning system
HRV	high resolution visible (refers to sensors in SPOT satellite)
m	meter
MD-DNR, DNR	State of Maryland, Department of Natural Resources
MSS	multispectral scanner
NASA	National Aeronautics and Space Administration
NCG	SCS National Cartographic and GIS Center
NWI	National Wetlands Inventory
NOAA	National Oceanic and Atmospheric Administration, U.S. Department of Commerce
PRE	project rating error
RMS	root mean square
SAV	submerged aquatic vegetation
SCS	Soil Conservation Service, U.S. Department of Agriculture
SPOT	Satellite Pour l'Observation de la Terre
SRSC	Space Remote Sensing Center, NASA
TM	Thematic Mapper
U.S.	United States of America
USGS	U.S. Geological Survey, U.S. Department of the Interior
UTM	Universal Transverse Mercator (a grid system based on the transverse mercator map projection)
μm	micrometer or micron (one-millionth of a meter)